
NASA's Mission Operations and Communications Services

**This Description applies to proposals in response to
NASA's Announcement of Opportunity for Discovery Missions**

AO 03-OSS

May 2003

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1.0 INTRODUCTION

This document is intended to assist in the preparation of proposals responding to the Announcement of Opportunity (AO) named on the Cover Page, which is issued by NASA's Office of Space Science (OSS). Its provisions are applicable in the post 2003 era.

NASA provides many operations and communications services for mission support. Costs accrue when using these services and estimates of these costs need to be included in proposals responding to the AO identified on this cover. To facilitate proposal preparation, proposers are encouraged to read this document and to contact the individuals named in Section 1.3 below.

1.1 Costing Policy

As a matter of policy, NASA includes estimated costs for mission operations and communications services, as well as an assessment of key parameters for mission operations, in the evaluation and selection processes of all Earth-orbiting and deep space missions. The Office of Space Science (the Enterprise) is implementing this policy to:

- implement formal NASA-wide full-cost accounting,
- better manage NASA's heavily subscribed communications resources,
- promote tradeoffs between on-board processing and storage vs. communications requirements, and
- encourage hardware and operations system designs minimizing life cycle costs while accomplishing the highest-priority science objectives.

1.2 Choice of Service Providers

NASA's Procedures and Guidelines (NPG) 7120.5B (Sections 2.1.5 and 3.1.5) require all programs/projects to develop requirements for space operations services provided by NASA facilities during mission formulation. Such services include communications, tracking, mission operations, navigation, and data processing. NPG 7120.5B requires projects to use NASA services unless a more cost-effective life cycle can be found and demonstrated in the proposal.

Programs/projects are free to propose procurement of services from sources other than NASA. Projects should conduct trade studies comparing the use of NASA-provided services with any proposed alternatives. NASA-initiated projects (e.g., missions in the OSS Strategic Plan) should conduct these studies in Phase A. Competitively selected projects (OSS PI class missions) may, at their option, conduct such studies in Phase A or Phase B.

Generally, NASA provided services should be employed whenever they meet mission objectives and have a life-cycle cost to the project and/or to the Enterprise, which is less than or equal to any of the proposed alternatives. Contact persons listed in Section 1.3.1.2 or 1.3.2.2 for assistance in identifying appropriate service, prices, and cost trades.

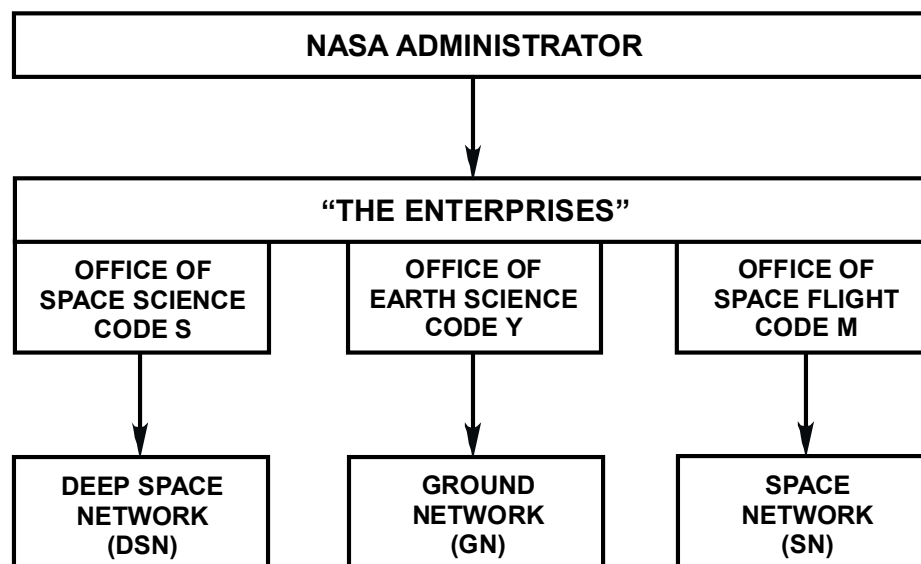
Where the Enterprise finds that the proposed project or PI approach does not result in the lowest life-cycle cost, the Enterprise may direct the project or PI to modify their approach. If utilizing NASA provided support services increases the project / PI costs, but reduces the cost to the Enterprise, any funding impacts to the project / PI will be resolved by the Enterprise.

If a trend towards project / PI-unique solutions appears to reduce individual mission cost but increases the total cost to NASA by not utilizing shared services and facilities, any resolution using the appropriate NASA-wide services strategy will be implemented in a manner in which the Enterprise shares in the cost savings.

1.3 NASA's Tracking Networks

NASA operates and maintains three separate tracking networks to support different types of missions. Starting in 2003, the functional management of NASA's Earth station and Space network are assigned to different NASA Headquarters offices. Several past proposals have included Earth orbiting vehicles for which either NASA's Ground Network (GN) or Space Network (SN) would be more suitable than the Deep Space Network (DSN). For that reason, and to avoid early obsolescence of this document, a short description of each has been included. Functional responsibilities for NASA's three networks in the post 2003 time frame are shown in Figure 1-1.

Figure 1-1: NASA Network Functional Responsibility in Post 2003 Era



1.3.1 Interplanetary Network Directorate

The Interplanetary Network Directorate (IND) comprises the Deep Space Mission System (DSMS) and the Institutional Computing and Information Services (ICIS) organization located at the Jet Propulsion Laboratory (JPL). DSMS is the executive agent for the operations and engineering of the DSN and provides the technical expertise needed for flight projects to use the DSN. This expertise includes communications formats, antenna capabilities and performance limits, scheduling, loading and other operations considerations, and, in particular, maintaining the cost algorithm for use of the DSN. In addition, the DSMS develops, maintains and employs a set of tools and services known as the Advanced Multi-Mission Operations System (AMMOS) for working with the DSN. Most spacecraft operating in deep space ($r \geq 2 \times 10^6$ km, Category B missions) will require support from the DSN.

1.3.1.1 DSMS Services

DSMS capabilities have moved from a facilities-based support model to one based upon standard services. Detailed descriptions of these standard services can be found in the *DSMS Services Catalog* (Reference 6). These services support both Earth orbiting and deep space science missions. Table 1-1 lists the DSMS Service Categories found in Reference 6. Each of the Service Categories named in Table 1-1 may contain several services. Some of those individual services may require that special arrangements be made with JPL before they can be provided. Proposers outside JPL who are interested in services that are not a part of the standard TT&C set should contact the person named in Section 1.3.1.2 for additional information. See Table 2-1 for a list of standard DSMS services included in the *Aperture Fee*.

Table 1-1: DSMS Service Categories

Service Category ¹	Brief Description of Service's Content
<i>Some services in the categories below are not a part of the basic TT&C set and require additional programmatic arrangements with JPL.</i>	
Command	RF modulation, transmission, and delivery of telecommands to spacecraft.
Telemetry	Telemetry data capture and additional value-added data routing and processing.
Mission Data Management	Data buffering, staging, short and long term storage.
Tracking and Navigation	Radio metric data capture, LEOP trajectory, ephemerides, and modeling.
Experiment Data Products	Level 1 & higher data processing providing photo and science visualization products.
Flight Engineering	Telecommunications link performance, analysis, and prediction and time correlation.
Beacon Tone	Monitors subcarrier frequencies transmitted by S/C indicating S/C's health.
Ground Communications	Data, voice, and video communications network services.
Radio Science	S/C Doppler, range, and open-loop receiver measurements at 2, 8, and 32 GHz.
Radio Astronomy / VLBI	Similar to Radio Science but measures natural phenomena. Wide & narrowband VLBI.
Radar Science	Transmits RF carrier toward user defined target; captures reflected signal.
Notes: 1. See DSMS Services Catalog (Reference 6) for details of services contained in these categories.	

1.3.1.2 Process for Requesting DSMS Services

Proposers should contact the person named below for information about DSMS mission operations services and costs at the time when initial science operations concepts are being defined. A DSMS representative will assist proposers by providing information concerning services and costs. Further, they will assist in documenting initial DSMS requirements in a *preliminary* DSMS Service Agreement (DSA, formerly the PSLA).

During the study phase, as the mission's concept is more clearly defined, requirements in the preliminary DSA are revised. The resulting documentation of services and costs become the DSA to be signed by appropriate Project and Network representatives. DSA's identify all mission operations requirements, including those provided by non-DSMS sources, becoming a source of end-to-end operations information and documenting any cost analyses leading to the selection of non-DSMS services.

The primary DSMS point of contact for this AO is the Plans and Commitments Office Manager (Organization 920):

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1.3.2 Ground Network

In 2003 and thereafter, Ground Network (GN) operations are the responsibility of Goddard Space Flight Center (GSFC) in Greenbelt, Maryland under the auspices of the Office of Earth Science (see Figure 1-1 above). The GN has Earth stations located in the United States at: Poker Flat, Alaska; Merritt Island, Florida; Wallops Island, Virginia; as well as in Antarctica, Chile, and Norway. Antenna sizes range from 2M to 18M in diameter. Generally, these stations support non-deep space (Category A) missions in the 2 and 8 GHz bands; however, several are capable of receiving signals from deep space (Category B) missions as well. Earth station antennas range in size from 2.4 to 18 meters in diameter. Table 1-2 shows several of the service categories.

1.3.2.1 GN Services

GN service categories are similar to those of the DSN listed above in Table 1-1, but include several *value added* services not found in the DSN. Additionally, several design services are available to assist mission planners in their conceptual design phase. Table 1-2 summarizes the GN services.

Table 1-2: GN / SN Service Categories

GN / SN Service Category	Brief Description
Commanding	RF modulation, transmission, and delivery of telecommands to spacecraft.
Telemetry	Telemetry data capture, decoding, and additional value-added data routing.
Tracking	Radio metric data capture (range, Doppler, and angles).
Mission Planning	Communications design, orbital modeling, scheduling, resource planning.
Flight Operations	Planning, controlling, and monitoring of operational spacecraft.
Flight Dynamics	Design spacecraft trajectory, predict and control of operational spacecraft.
Science Data Processing	Processing of science data, generate data products, analysis of data.
Consulting and Training	Anomaly resolution, troubleshooting, consulting.
Range Support	Control center, range communications, meteorology, launch imagery.
System Performance & Test	Telecommunications interface design, compatibility testing.
System Procedure Develop	Develop detailed processes & procedures for S/C operations.
Special Operations	Non-routine flight ops. Including: anomalies, contingencies & emergencies.

1.3.2.2 Process for Requesting GN and SN Services

At the time when initial science operations concepts are being defined, proposers should contact the person named below for information about GN mission operations services and costs. A representative assists proposers by providing service and cost information. Further, the Customer Commitment Office aids in documenting initial mission operations requirements in a preliminary Project Support Level Agreement (PSLA).

During the study phase, as the mission's concept is more clearly defined, requirements in the preliminary PSLA are revised. The resulting documentation of services and costs become the PSLA to be signed by appropriate Project and Network representatives.

The GN and SN point of contact for this AO is the GSFC Customer Commitment Manager:

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1.3.3 Space Network

In 2003, NASA's Space Network (SN) becomes the responsibility of the Space Communications and Data Systems (SCDS) Office. Located within Code M (see Figure 1-1), SCDS is accountable for NASA's Tracking and Data Relay Satellite System (TDRSS). TDRSS operates in the 2 and 13-15 GHz bands and there are plans to extend operations to the 26 GHz band. NASA's SN is generally compatible with the National Space Development Agency's (NASDA's) data relay satellite system for the Mult-Access system operating in the 2 GHz band.

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1.3.3.1 Space Network Services

NASA's Space Network (SN) consists of seven geosynchronous satellites located at: 275° W, 174° W, 171.3° W, 171.1° W, 49° W, 47° W, and 41° W. Satellite control and data capture facilities are located in: Guam (GRGT), Goddard Space Flight Center in Greenbelt, MD and White Sands, New Mexico (STGT and WSGT).

Second generation Tracking and Data Relay Satellites (TDRSs) offer enhanced Multiple Access (MA) capability and higher data rates on the S-band (6 Mbps) and K_A-band (800 Mbps) Single Access (SA) channels.

SN service categories follow those for the GN outlined above in Section 1.2.3.1 and readers should refer to Table 1-2 for the list.

1.3.3.2 Process for Requesting SN Services

At the time when initial science operations concepts are being defined, proposers should contact the person named in Section 1.3.2.2 above for information about SN mission operations services and costs. A representative assists proposers by providing service and cost information. Further, the Customer Commitment Office aids in documenting initial mission operations requirements in a preliminary Project Service Level Agreement (PSLA).

During the study phase, as the mission's concept is more clearly defined, requirements in the preliminary PSLA are revised. The resulting documentation of services and costs become the PSLA to be signed by appropriate Project and Network representatives. A point of contact for SN services can be found in Section 1.3.2.2 above.

1.4 Standards

It is NASA policy that space missions receiving funding from NASA comply with all international and United States regulations, standards, and agreements. Such regulations and standards include those promulgated by the:

- International Telecommunications Union (ITU)
- National Telecommunications and Information Agency (NTIA)
- Consultative Committee for Space Data Systems (CCSDS)
- Space Frequency Coordination Group (SFCG)

Information about the ITU and NTIA regulations may be obtained from NASA's Spectrum Management Office at the Glenn Research Center or by consulting References 1 and 2. Recommended CCSDS standards applicable to DSN, Ground Network, or TDRSS support can be found in Reference 3, the CCSDS home page. Recommendations of the SFCG are available in Reference 4.

1.5 Policies

Capabilities described below result in the more efficient use of NASA's facilities. Where it is determined not to utilize an item, the proposal should include the rationale for its omission. Explanations are particularly important in Step 2 proposals. Networks to which each item is applicable are noted following the subsection's title.

In addition to providing the operations and communications services costs as required by Section 1.1 and complying with the standards listed in Section 1.4 above, there are other NASA policies affecting proposal content. Proposers should carefully consider each item below.

1.5.1 Space Link Extension (DSN, GN, SN)

Project Operation Control Centers (POCCs) using DSN and SN services should utilize a standard *Space Link Extension (SLE) Services Interface* for transferring data to and from DSN or SN sites. This interface is designed to provide international control center-network interoperability and reduce mission risk by facilitating the rapid substitution of a different earth station, not necessarily only NASA's, in the event of a failure. In 2005 and beyond, the SLE Services interface will require POCCs to directly access DSN stations for the following services: Command Link Transmission Unit (CLTU), Return All Frames (RAF), Return Channel Frames (RCF), and CCSDS File Delivery Protocol (CFDP). Proposers interested in SN or GN services should contact the person named in Section 1.3.2.2.

Seven international space agencies, including: ASI, CNES, DLR, ESA, ISAS, NASA, and NASDA, have agreed to implement the SLE Services Interface to achieve full international interoperability. Interface architecture conforms to standards adopted by the CCSDS (Reference 3). It will be operational in the DSMS on or before October 2002 and missions launching after that date should plan to use this system.

1.5.2 X-Band and K_A-Band Communications (DSN, GN, SN)

Category B ($r \geq 2 \times 10^6$ km) missions operating in a *Space Research* allocation launching after 2002 should be designed to communicate in either the 7/8 GHz or 7/32 GHz bands. Ever increasing congestion and the addition of allocations for incompatible services (e.g., IMT-2000) have restricted future operations in the 2 GHz deep space band. Accordingly, the Office of Space Science is recommending that use of the 2 GHz deep space band be limited to radio science and in-situ communications. Deep space missions having high data rates should operate in K_A-Band (31.8 - 32.3 GHz space-to-earth) or, if using the 8400-8450 MHz band, they should comply with SFCG Recommendations regarding bandwidth-efficient modulation. Approved methods for bandwidth efficient modulation can be found in Reference 3.

Category A ($r < 2 \times 10^6$ km) missions also have an allocation for the *Space Research* service in the 7190 - 7235 MHz (Earth-to-space) and 8450 - 8500 MHz (space-to-Earth) bands. Because of the congestion in the 2 GHz band from ever increasing use, proposers are encouraged to use the 7/8 GHz bands whenever possible. Missions operating in either the 2 or 7/8 GHz bands should comply with the spectrum emissions mask in the SFCG Handbook (Reference 4). Approved methods for bandwidth efficient modulation can be found in Reference 3.

Category A Missions with high data/symbol rates planning to operate in the 8 GHz *Earth Exploration Satellite* (EES) (8025 - 8400 MHz) should investigate capabilities in the 26 GHz band. Missions utilizing the EES service tend to have very high data/symbol rates and all missions planning to operate in the 8 GHz band should comply with the spectrum emissions mask in the SFCG Handbook (Reference 4). Approved methods for bandwidth efficient modulation can be found in Reference 3.

Additionally, a new allocation for the *Space Research* service is being requested in the 25.5 - 27.0 GHz band (a.k.a. 26 GHz band) at the World Radio Conference (WRC) in 2003. If this new allocation is adopted at WRC 03, high data rate space science missions, requiring bandwidths in excess of 10 MHz, should be designed to operate in the 26 GHz band.

1.5.3 Bandwidth Efficient Modulation (DSN, GN, SN)

Missions operating in the 2 and 8 GHz bands (see Section 1.5.2), should employ bandwidth efficient modulation methods in conformance with SFCG and CCSDS Recommendations. Spectral Emission Masks for Category A missions are found in the Space Frequency Coordination Group's (SFCG's) Handbook, available on the SFCG web site (Reference 4). Specific modulation methods meeting the SFCG mask are enumerated in CCSDS Recommendations 401 (2.4.17A) B-1, and 401 (2.4.18) B-1 for non-deep space and Earth resources missions respectively (Reference 3).

As a matter of IND policy, it is recommended that Category B missions employ bandwidth efficient modulation whenever operating in the 8400 - 8450 MHz band at symbol rates above 2 Msps. CCSDS Recommendation 401 (2.4.17B) B-1 lists acceptable modulation schemes.

1.5.4 CCSDS File Delivery Protocol (DSN, GN, SN)

To improve station utilization efficiency as well as reduce mission risk and costs, all DSN users should employ the CCSDS File Delivery Protocol (CFDP), to transfer data to and from a spacecraft. CFDP operates over a CCSDS conventional packet telecommand, packet telemetry, or an Advanced Orbiting System (AOS) Path service link. CFDP enables the automatic transfer of a complete set of specified files and associated information from one storage location to another replacing an expensive labor-intensive manual method. It can transfer a file from a source point to a destination site using an Automatic Repeat Queuing (ARQ) protocol. In an *acknowledged mode*, the receiver notifies the transmitter of any undelivered file segments or ancillary data so that the missing elements can be retransmitted guaranteeing delivery. An *unacknowledged mode* is also permitted. CFDP information can be found in the *CCSDS File Delivery Protocol* Blue Book available under the *Advanced Orbiting Systems* category on the CCSDS web site (Reference 3).

1.5.5 Multiple Spacecraft Per Antenna (DSN)

Where a multiplicity of spacecraft lie within the beamwidth of a single DSN antenna, it may be possible to capture data from two or more spacecraft simultaneously using the Multiple Spacecraft Per Aperture (MSPA) system. MSPA decreases DSN loading and will save the project's money (see Section 2.1.3).

There are a few constraints. First, only a single uplink frequency can be transmitted. Generally, this means that only one spacecraft at a time can operate in a two-way coherent mode, while the remainder must be in a one-way (i.e., non-coherent) mode. Second, multiple-independent receivers are required at the Earth station. This sets a practical limit on the number of spacecraft that can be served simultaneously. Initially, that number is two, but by 2007 it is expected to be four. Third, ranging and two-way coherent Doppler data can only be obtained from the single spacecraft operating in a two-way coherent mode.

Approximately 30-minutes are required to transfer two-way coherent operations from one spacecraft to another irrespective of whether or not the spacecraft, which will be in the two-way coherent mode, is currently part of the MSPA cluster. When switching the uplink from one spacecraft to the next, full *Aperture Fee (AF)* costs apply to the new two-way coherent user at the onset of the switching operation. Transfers of two-way coherent operations requires:

- 1) Tuning the uplink of the spacecraft in a two-way coherent mode to its rest frequency,
- 2) Setting the station uplink frequency to the next spacecraft's and acquiring the uplink,
- 3) Reconfiguring the command subsystem (if required) for the next spacecraft,
- 4) Reconfiguring ranging (if required) for the next spacecraft,
- 5) Reconfiguring the Monitor and Control subsystem,
- 6) Relocking the Earth station's receiver and telemetry processor following the switch.

For a Project to avail itself of the MSPA savings, the following conditions must apply:

- 1) All spacecraft must lie within the beamwidth of the requested antenna.
 - a. Projects must accept reduced link performance from imperfect pointing.
- 2) Spacecraft downlinks must operate on different frequencies.
- 3) Only one spacecraft at a time can operate with an uplink in a coherent mode.
 - a. Commands can only be sent to the spacecraft receiving an uplink.
 - b. Ranging & coherent Doppler are available from the spacecraft in a 2-way mode.
 - c. Remaining spacecraft transmit 1-way downlinks with telemetry only.

1.5.6 Delta Differenced One-Way Range (DSN)

Delta Differenced One-Way Range (DDOR) can be used in conjunction with Ranging and Doppler data to:

- 1) Increase spacecraft targeting accuracy (when used with range and Doppler data).
- 2) Improve mission reliability (when used with range and Doppler data).
- 3) Reduce tracking time (if pass duration is driven by tracking data capture).

Projects should investigate whether this data type offers sufficient improvement in one or more of the above parameters to justify the cost in terms of spacecraft implementation, operational complexity, and Earth station scheduling. Under the proper conditions, (DDOR) can offer significant benefits including a reduced mission cost.

For (DDOR) to be usable:

- 1) The spacecraft must transmit two tones (the greater the frequency separation the better).
- 2) Two DSN Earth stations must observe the spacecraft and natural radio sources.

1.5.7 Relayed Data (DSN)

Some missions may propose dropping probes, landers, or even rovers to explore the surface of a planet. Others may insert orbiters around the same body. The result can be a multiplicity of spacecraft on or around a planet. While Mars has been the recent focus, it is foreseeable that other planets or objects in space could be of equal interest in the future.

Where several spacecraft are relatively close together and positioned far from the Earth, it makes sense to send data to and from small vehicles via a relay (Proximity Link). Typically, this has been an orbiting spacecraft carrying a special transceiver operating at UHF frequencies. Relaying data from surface objects can save money and reduce size and power requirements of landed equipment. Proposals for landed objects in the vicinity of an orbiting spacecraft should consider whether a data relay makes sense for their application. Some *Announcements of Opportunity* (AOs) have required orbiting spacecraft with certain characteristics to carry Proximity Link hardware. A specific relay link design [Proximity Link] has been adopted by the CCSDS and its specifications can be found in Reference 3.

1.5.8 Coding

Most missions employ error detecting – error correcting codes to substantially improve telemetry link performance. DSMS users are reminded that their encoders should conform to the *CCSDS Telemetry Channel Coding* Blue Book (CCSDS 101.0-B-5, June 2001). Acceptable codes include: 1) Convolutional $r = \frac{1}{2}$, $k = 7$ only; 2) Reed-Solomon 223/255 only; 3) concatenated Convolutional / Reed-Solomon and 4) Turbo codes with rates: $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, or $\frac{1}{6}$, block sizes: 1784, 3568, 7136, and 8920.

2.0 NETWORK SUPPORT COSTS

Generally, mission proposals must include both launch and support costs. This section explains how to obtain costs for the DSN, GN, SN, and AMMOS.

2.1 Costs for Using the Deep Space Network

Proposed Category B missions operate in deep space and frequently have lower signal levels and restricted communications bandwidths, as compared to missions orbiting close to Earth. In developing their mission concept, proposers should perform trade-offs among the elements of the end-to-end data system. The elements include instrument format design, flight data system, the space communications features, and the several elements of the ground data system. The integrated contact time and the contact frequency of the spacecraft with the DSN are typically important parameters in these trade studies. To simplify DSN costing, an algorithm has been developed permitting users to calculate the *DSN Aperture Fee* and included services.

The DSN consists of control, communications, test facilities at JPL, and Earth station complexes located near Goldstone, California; Canberra, Australia; and Madrid, Spain. The DSN provides communications services between spacecraft and Earth station complexes together with the ground communications among the complexes and the DSN control center located at JPL in Pasadena, California.

Testing to establish compatibility between the spacecraft's Radio Frequency Subsystem (RFS) and DSN stations is available at the Development Test Facility (DTF-21) at JPL in Pasadena or by using the Compatibility Test Trailer (CTT) at a remote site. RFS compatibility testing is highly recommended and should be completed about eighteen months prior to launch.

DSN 26-meter, 34-meter, and 70-meter diameter antennas operating in the 2, 7, 8, and 32 GHz bands provide radio frequency communications. User costs vary with aperture size and utilization level. Generally, DSN services are included in the *Aperture Fee* (see Equation 2-1 below).

2.1.1 DSN Aperture Fees

Cost numbers supplied in this Section are for planning purposes only. To ensure accurate application of this information and to validate cost estimates please contact the DSMS representative listed in Section 1.3.1.2. DSMS personnel should always be consulted to validate these costs in Step 2 proposals.

The algorithm for computing DSN *Aperture Fees* embodies incentives to maximize DSN utilization efficiency. It employs *weighted hours* to determine the cost of DSN support. The following equation can be used to calculate the *hourly Aperture Fee* (AF) for DSN support.

$$AF = R_B [A_W (0.9 + F_C / 10)] \quad (2-1)$$

where:

AF = weighted *Aperture Fee* per hour of use.

R_B = contact dependent hourly rate, adjusted annually (\$842/hr. for FY03).

A_W = aperture weighting:

= 0.80 for 26-meter or 34-meter High-Speed Beam Waveguide (HSB) stations.

= 1.00 for all other 34-meter stations (i.e., 34 BWG and 34 HEF).

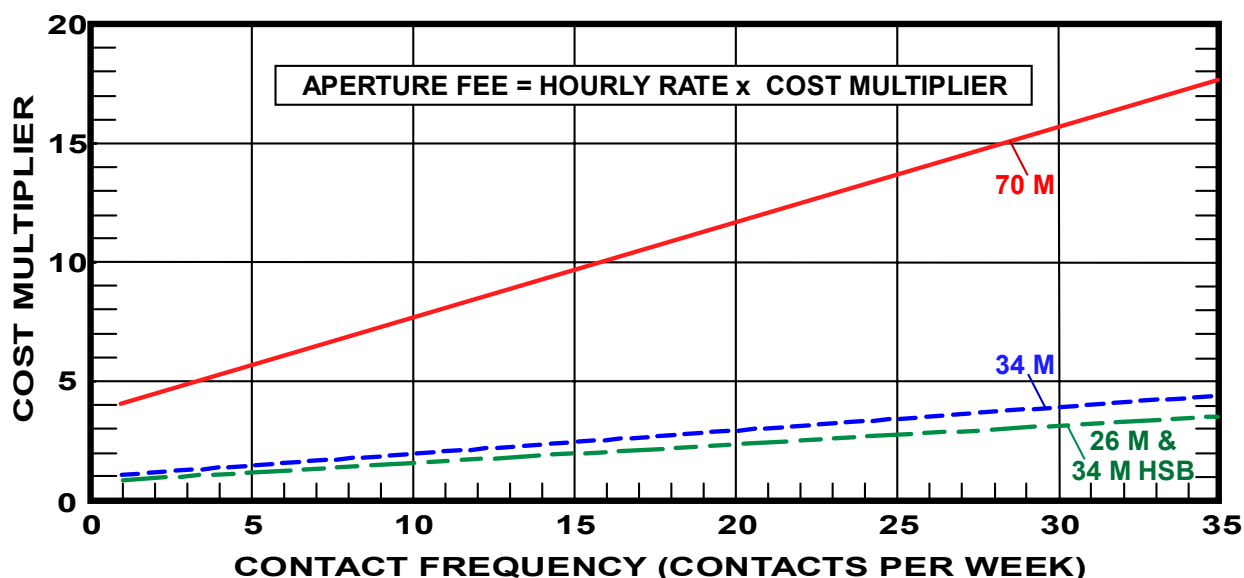
= 4.00 for 70-meter stations.

F_C = number of station contacts, (contacts per calendar week).

The *weighting factor* graph below shows relative antenna costs. It graphically illustrates how *hourly costs* vary with *station contacts* and the relationships between antennas. It demonstrates the benefits of restricting the number of spacecraft-Earth station contacts each week.

A station contact, F_C , may be any length but is defined as the lesser of the spacecraft's: scheduled pass duration, viewperiod, or 12 hours.

For a *standard pass*, a 45-minute pre-configuration and a 15-minute post-configuration time must be added to each scheduled pass to obtain the *station contact* time (other configuration times apply to Beacon Monitoring and Delta-DOR passes – see relevant cost sections below). Note that scheduled pass-lengths should be integer multiples of 1-hour.



Total DSN cost is obtained by partitioning mission support into calendar weeks, grouping weeks having the same requirement in the same year, multiplying by weighted *Aperture Fee*, and summing these fees over the mission's duration. *Aperture Fees* include several services in the following categories: command, telemetry, tracking and navigation, radio science, radio astronomy, radar science, routine compatibility testing, and TMS Manager.

2.1.2 DSN Costing Calculations

Calculate DSN costs (*Aperture Fee*, *AF* in \$/Hr.) by selecting a specific antenna and then determining the number and duration of tracking passes required to satisfy project commanding, telemetry, and navigation for launch, cruise, TCM, and science phases. Each tracking pass, except Beacon Mode, DDOR, and a few others must be increased in length by one-hour for re-configuration. Once the pass length and number of passes is determined, multiply the aggregate hours by the hourly *Aperture Fee*, adjusted to the applicable *fiscal year*, to compute the mission's cost (in FY Dollars) using equation (2-1).

A form, entitled Table 2-2: *DSN Mission Support Costs*, can be used to calculate DSN *Aperture Fees* in real-year or fiscal year Dollars. An Excel 2000 personal computer program is available for the preparation of the cost estimates. To obtain a copy, either contact the person named in Section 1.3.1.2 or the DSMS Future Missions Planning Office web site (Reference 5).

2.1.2.1 Included Services

Several value added services are available from the DSN and are included in the *Aperture Fee*. Table 2-1 names those services. For additional details, consult Reference 6.

Table 2-1: Services Included in DSN Aperture Fee

Service	Service
Command 1. Command Radiation 2. Command Delivery	Ground Communications 1. Ground Network 2. Data Transport
Telemetry 1. Frame 2. Packet 3. Telemetry File	Radio Astronomy / VLBI 1. Signal Capturing 2. VLBI Data Acquisition 3. VLBI Correlation
Mission Data Management 1. Short Term Data Retention	Radio Science 1. Experiment Access 2. Data Transport
Tracking & Navigation 1. Validated Radio Metric Data 2. Delta-DOR 3. Ephemerides 4. Modeling & Calibration	Radar Science 1. Experiment Access 2. Data Acquisition
	Beacon

DSN SUPPORT SUMMARY	
Total Station Cost:	
TMS / NOPE Cost:	No Add'l. Chg.
Additional Fees:	
Total DSN Hours:	
Total R-Y Support Cost:	
Total F-Y Support Cost:	

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2.1.3 Multiple Spacecraft Per Antenna DSN Costing - DSN Fee Reduction

Some flight programs, such as those surveying Mars, have clustered several spacecraft about a planet. It is possible to simultaneously capture telemetry signals from two or perhaps more spacecraft provided that they lie within the beamwidth of the Earth station's antenna.

If this situation applies and the constraints, set forth here and in Section 1.5.5, are acceptable, then it may be possible to reduce the Antenna cost by half for spacecraft operating without an uplink in a non-coherent mode. To calculate the cost, first compute the *Aperture Fee* using equation 2-1 above. Thereafter, apply the correction factor according to the formula:

$$AF' = (0.50) AF \quad (2-2)$$

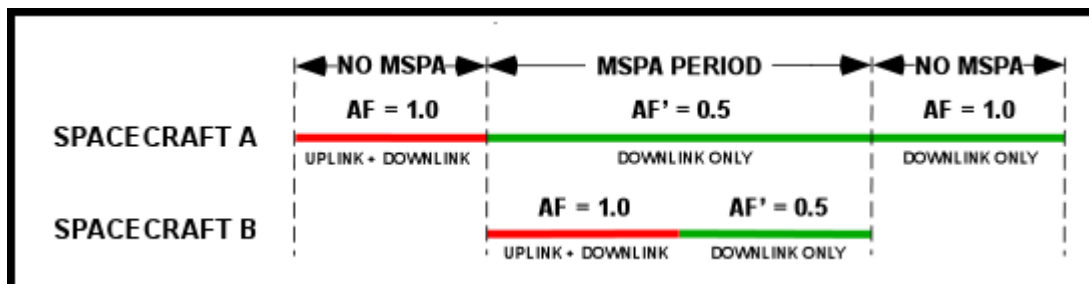
where: AF' = weighted *Aperture Fee* per hour of use for spacecraft operating without an uplink in the MSPA mode. (Spacecraft having an uplink when operating in an MSPA mode should use the aperture fee (AF) computed according to equation 2-1.)

The reduced price, AF' , reflects the lack of capability resulting from no uplink communications. It is based upon the loss of commanding and ranging services to the spacecraft operating in a one-way non-coherent mode. If MSPA users agree, all could time-share the uplink and then re-allocate cost savings according to their individually negotiated sharing arrangements. When switching the uplink from one spacecraft to the next, full costs, AF , begin to apply to the new two-way coherent user at the onset of the switching operation.

Note: MSPA exists if, and only if, the same DSN antenna is simultaneously supporting two or more spacecraft without regard to whether an uplink is required by either.

Some examples may prove helpful. If a single DSN antenna is capturing telemetry from two spacecraft simultaneously, one with an uplink and the other in a one-way mode, the one with the uplink is at full cost (AF) [equation 2-1] while the other without the uplink calculates its cost at $AF' = 0.5 AF$. Where neither of the two spacecraft has an uplink, then each pays an *Aperture Fee'* (AF') of $0.5 AF$. If the pass of one spacecraft begins before the other, or lasts beyond another, then there is no MSPA and that user is charged the full *Aperture Fee*, AF irrespective of whether there is an uplink. Figure 2-1 may help to clarify the rules.

Figure 2-1: MSPA Aperture Fee



Note: Proposals employing the MSPA reduced-cost algorithm should also include Letter(s) of Agreement from the other simultaneous MSPA users stating the relevant conditions including how the uplink will be shared (see Section 3.3).

2.1.4 Clustered Spacecraft Aggregated DSN Costing

Occasionally a mission comprises several spacecraft flying in a geometric formation, but with spacing too large to utilize MSPA. Rather than request simultaneous support from several DSN stations, the project may agree to sequentially contact each spacecraft. From a project viewpoint, it is desirable to treat sequential DSN communications with several spacecraft as a single DSN contact for costing purposes. This section outlines the conditions when aggregation is permitted.

DSN *station configuration* is a key element in establishing the continuous nature of a contact. If a new configuration is required for each spacecraft in the cluster, then support of several spacecraft assumes the character of individual contacts arranged in a sequential order. Conversely, if everything at a DSN station, except the direction in which the antenna is pointing remains fixed when transitioning to a different spacecraft, the essential character is one of a single contact.

Station configuration involves loading predicts containing: transmit and receive frequencies, Doppler frequency estimates, spacecraft identification numbers, data routing information, measuring station ranging delay, etc. These may be unnecessary when the several spacecraft:

- Operate on the same frequency,
- Have the same spacecraft identification number,
- Require identical data routing, and
- Do not utilize ranging.

For missions consisting of a multiplicity of spacecraft, each of which receives commands and/or transmits telemetry sequentially to and from a single DSN Earth station in a series of contiguous communications, then aggregation of individual pass times into a single contact may be reasonable. For purposes of cost calculations, a *station contact* is as defined in Section

2.1.1. Clustered Spacecraft Aggregated DSN Costs are calculated by:

- Adding a single pre-configuration and post-configuration time for the aggregated period,
- Including costs for time needed to move the spacecraft from one spacecraft to the next,
- Treating the series of links during a pass as a single contact for the costing algorithm,
- Computing the cost following equation 2-1 in Section 2.1.1.

All missions consisting of a cluster of spacecraft not meeting the above criteria should calculate their costs using equation 2-1 in Section 2.1.1 treating each sequential communication with a member of the cluster as a separate and individual contact.

2.1.5 Data Relay DSN Costing

Data between a landed object and a DSN station, which is relayed through an orbiting spacecraft, may be unaccompanied or interspersed with data from other sources. At any specific time, a DSN station may be communication with one or more surface objects.

Proposals for missions employing relays should include their pro-rata share of the DSN station cost. Pass cost can be found by calculating the time required to return the total amount of relayed data, assuming that only this data being transmitted from the orbiting relay element or by assuming 1-hour, whichever is greater. Station configuration times need not be considered; however the *base rate* is increased depending upon the number of relay passes per week according to equation (2-1). Proposals should state their rationale and assumptions for their computed share of the DSN cost carefully, completely, and in sufficient detail so that evaluators can independently verify the computations.

2.1.6 DDOR DSN Costing

Under the correct geometric circumstances, Delta-Differenced One-way Range (DDOR) can result in a net reduction in needed tracks (see Section 1.5.6). This is so because adding DDOR passes can reduce the number of contacts needed to collect long data arcs of coherent Doppler and ranging measurements necessary to compute a spacecraft's trajectory. DDOR can also be used as an independent data source to validate orbit solutions. However, two widely separated earth stations are required simultaneously to view the spacecraft and the natural radio sources.

DSN 34M and 70M stations can be used to collect DDOR data. To calculate a cost for a DDOR pass, users should determine the: 1) DSN stations desired for the DDOR pass, 2) Amount of DDOR data required to obtain the spacecraft's position, 3) Pass length needed to obtain the data, 4) Pre-configuration time of 90-minutes (a 45-minute *standard pass* pre-configuration period for the station plus an additional 45-minutes for DDOR). The post-configuration time remains at 15-minutes for each DDOR pass (*Note: This is 90-minute pre-configuration plus 15-minutes post-configuration time for each station in the DDOR array.*), and 5) Cost of the pass by summing the cost for the two desired DSN stations plus pre- and post configuration times over the length of the pass.

2.1.7 Beacon Tone Monitoring DSN Costing

Beacon Tone Monitoring is a low-cost method for verifying spacecraft health. A spacecraft transmits up to four predetermined tone frequencies (subcarriers) indicating its current condition. Spacecraft must be designed to monitor their subsystems and direct an appropriate tone be transmitted. Beacon Tone Monitoring is particularly useful during long cruise periods when little or no science data is being collected.

Beacon Tone tracks (exclusive of configuration time) are generally short (40 to 60-minutes) and must occur at pre-scheduled times when the spacecraft is in view of a DSN complex. DSMS 34M or 70M stations capture tones and project personnel are informed of the frequency received. They, not DSMS personnel, must determine the meaning of the received tone.

Because no science or housekeeping data is received, it is possible to reduce the configuration times and hence cost for Beacon Tone Monitoring. Proposers calculating a cost for Beacon tone Monitoring should compute *Aperture Fee (AF)* for the requested DSN antenna using a pre-configuration time of 15-minutes and a post-configuration time of 5-minutes (rather than 45-minutes and 15-minutes respectively). The minimum pass length, including configuration times, is 1-hour (40-minute pass plus 20-minutes of pre- and post-configuration time).

2.1.8 Compatibility Testing DSN Costing

DSMS encourages pre-launch compatibility testing as a means to eliminate post launch anomalies and expensive troubleshooting. DSMS maintains a facility known as the Development Test Facility (DTF-21) in Pasadena, California. Except for the high power transmitter, antenna, and low noise-receiving amplifier, which are not included, DTF-21 is configured much like an operational DSN Earth station.

Approximately eighteen months prior to launch, projects should bring their Radio Frequency Subsystems (RFS) to DTF-21 for testing. Testing requires approximately two weeks and includes such items as RF compatibility, data flow tests, and transponder calibration.

Because DSMS believes that this testing materially improves the likelihood of mission success, no charge is made for the use of these facilities for a single set of compatibility tests. Rather, it is included in the hourly-dependent rate, R_B , used in Equation 2-1.

2.2 Advanced Multi-Mission Operations System Costing

Advanced Multi-Mission Operations System (AMMOS) elements are located at JPL; however, specific subsystems may also be placed at user sites. AMMOS offers a selection of services and tools for spacecraft command and control, data reduction and analysis, and navigation. DSMS services are integrated, and certain DSN services may be a prerequisite to obtaining AMMOS value-added services. Proposals should identify required AMMOS services. For information and/or cost of these services, contact the person named in Section 1.3.1.2 (or see Reference 6 for service descriptions).

In addition to its standard services, AMMOS can provide users with specific software tools. Such tools include telecommand encapsulation and protocol verification, mission analysis software, spacecraft monitoring programs, and data analysis software. For a description of the *Tools* available, please see the *DSMS Services Catalog*, available on the IND Future Missions Planning Office web site (Reference 6).

Because each mission is unique, it is difficult to provide *a priori* tool prices. Generally, AMMOS personnel need to confer with project personnel to determine specific tool requirements. Thereafter, it should be possible to quote a price for the product. If a tool's specification is completed by the end of Phase B, then work can commence at the start of Phase C/D so that the tool will be available at launch.

2.3 Ground Network and Space Network Costing

GN and SN services are highly mission dependent. Therefore, it is not possible to provide a simple cost structure such as the one used for DSMS stations. Proposers are advised to contact the GSFC Customer Commitment Office listed in Section 1.3.2.2 above to obtain a cost estimate for their mission.

3.0 REQUIRED PROPOSAL INFORMATION

Evaluation requires an independent assessment of systems proposed in response to the AO to verify the claims made. Absent the necessary information, evaluators are compelled to *assume* values for missing parameters based upon their knowledge and experience. Conservative assumptions by an evaluator can work to the detriment of proposers. Accordingly, proposers are requested to provide the information in the following Tables and subsections so that evaluators can make the necessary calculations. This is particularly important in Step 2 of the proposal process.

3.1 Communications System Parameters

As a minimum, proposals should contain the set of telecommunications parameters shown in Table 3-1. While proposers may or may not wish to use a tabular format, the required parameter values should be supplied in a clear, concise, and readily apparent form.

Table 3-2 is a sample telecommunications link parameter form containing the necessary 26 parameters but using only 1/3 of a page. Proposers are requested to include this completed form in their proposals.

If a proposal does not contain sufficient information for an evaluator to independently verify that each communication's link operates properly, a negative finding is likely to be made.

3.2 Station Support Requirements

Proposers should clearly state their DSN support requirements, preferably in a tabular format. For all mission phases (e.g., launch, cruises, TCMs, flybys, orbit insertion, orbit operations, data return, etc.) proposals should show the mission's phase, the year in which the support is desired, station required, pass length in hours, number of passes each week, and the number of weeks that this support is required. A sample table containing a few entries for a fictitious planetary mission appears in Table 3-3. Proposers are requested to include a completed form showing all major mission phases and the support required in their proposals.

3.3 MSPA User(s) Information

Missions planning to employ MSPA can reduce their costs by using shorter track lengths and operating in a non-coherent one-way mode, provided that they do not require an uplink (see Section 2.1.2). However, Step 2 proposers planning to avail themselves of such savings should include a Letter(s) of Agreement from each of the other projects with whom they will be sharing the MSPA capability stating how the uplink services (e.g., commanding, coherent radio metric data capture, etc.) will be shared.

Absent such Letter(s) of Agreement, reviewers will employ their judgment as to whether the proposed MSPA utilization is within "reasonable" levels.

Table 3-1: Telecommunications Parameters and Definitions

Parameter	Units	Description
Maximum S/C Distance	Km	Maximum spacecraft-earth station distance during primary mission.
1 st Encounter Distance	Km	Maximum spacecraft-earth station distance during first encounter.
2 nd Encounter Distance	Km	Maximum spacecraft-earth station distance during second encounter.
N th Encounter Distance	Km	Maximum spacecraft-earth station distance during Nth encounter.
Uplink Transmitter Power	Watts	Earth Station Transmitter Output.
Uplink Frequency Band	GHz	Proposed earth-to-space frequency band expressed in GHz.
Uplink Command Mod. Index	Rad	Earth Station Uplink Command Modulation Index (Radians)
Uplink Ranging Mod. Index	Rad	Earth Station Uplink Ranging Modulation Index (Radians)
Uplink Transmit Antenna Gain	dBi	Gain (or name) of earth stations transmitting antenna (e.g., 34M BWG).
S/C HGA Receive Gain / Loss	dBi/dB	Gain of spacecraft's high-gain receive antenna / Circuit loss to LNA.
S/C MGA Receive Gain / Loss	dBi/dB	Gain of spacecraft medium-gain receive antenna / Circuit loss to LNA.
S/C LGA Receive Gain / Loss	dBi/dB	Gain of spacecraft low-gain receive antenna / Circuit loss to LNA.
Telecommand Data Rates	b/s	Maximum and Minimum desired telecommand data rate (Max / Min).
Telecommand Bit-Error-Rate	-	Required telecommand Bit-Error-Rate (BER).
S/C Receiver Noise Temperature	K	Total spacecraft receiver system noise temperature.
S/C Receiver Bandwidth	Hz	S/C Receiver's phase-locked-loop threshold bandwidth (2 Blo).
Turnaround Ranging	Yes/No	Statement whether turnaround ranging is required.
Required Ranging Accuracy	Meters	Specify project's required range measurement accuracy.
SC Transmitting Power	Watts	S/C Power amplifier output.
Downlink Modulation Format	Name	Format name (e.g., PCM/PM/Bi-φ, PCM/PSK/PM, BPSK, QPSK, etc.).
Downlink Frequency Band	GHz	Proposed space-to-earth frequency band expressed in GHz.
S/C HGA Transmit Gain / Loss	dBi/dB	Gain of spacecraft's high-gain transmit antenna / Circuit loss from PA.
S/C MGA Transmit Gain / Loss	dBi/dB	Gain of spacecraft's medium-gain transmit antenna / Circuit loss from PA.
S/C LGA Transmit Gain / Loss	dBi/dB	Gain of spacecraft's low-gain transmit antenna / Circuit loss from PA.
Downlink Receive Antenna Gain	dBi	Gain (or name) of earth station receiving antenna (e.g., 34M BWG) .
Telemetry Data Rates	b/s	Maximum and Minimum desired telemetry data rates (Max / Min).
Downlink Telemetry Mod Index	Rad	S/C Downlink Telemetry Modulation Index (Radians)
Telemetry Coding	Name	Telemetry code (e.g., convolutional, Reed-Solomon, concatenated, Turbo etc.).
Telemetry Frame Length	Bits	Total telemetry frame length, if Turbo encoded.
Frame Deletion Rate	Rate	Acceptable Transfer Frame deletion rate from bit errors.
Telemetry Bit-Error-Rate	-	Telemetry Bit-Error-Rate (BER) required for desired frame deletion rate.
Downlink Ranging Mod Index	Rad	S/C Downlink Ranging Modulation Index (Radians)

3.4 Other Information

The previous sections (1 and 2) set forth requirements for proposal content. Persons preparing proposals should carefully review all three sections to ensure that the document that they are submitting addresses each applicable item. This is particularly important in step two proposals.

Table 3-2: Sample Table for Inclusion in Proposal

Parameter	Value	Parameter	Value
Maximum S/C Distance (km)		Turnaround Ranging (Yes/No)	
1 ST Encounter Distance (km)		Required Ranging Accuracy (m)	
2 ND Encounter Distance (km)		S/C Transmitting Power (Watts)	
N TH Encounter Distance (km)		Downlink Modulation Format (Name(s))	
Uplink Transmitter Power (Watts)		Downlink Frequency Band (GHz)	
Uplink Command Mod. Index		S/C Downlink Telemetry Mod Index	
Uplink Ranging Mod. Index		S/C Downlink Ranging Mod Index	
Uplink Frequency Band (GHz)		S/C HGA Transmit Gain (dBi) / Loss (dB)	
Uplink Transmit Antenna Gain (dBi)		S/C MGA Transmit Gain (dBi) / Loss (dB)	
S/C HGA Receive Gain (dBi) / Loss (dB)		S/C LGA Transmit Gain (dBi) / Loss (dB)	
S/C MGA Receive Gain (dBi) / Loss (dB)		Downlink Receive Antenna Gain (dBi)	
S/C LGA Receive Gain (dBi) / Loss (dB)		Telemetry Data Rates (b/s)	
Telecommand Data Rates (b/s)		Telemetry Coding (Name)	
Telecommand Bit-Error-Rate		Telemetry Frame Length	
S/C Receiver Noise Temperature (K)		Frame Deletion Rate	
S/C Receiver Bandwidth (Hz)		Telemetry Bit-Error-Rate	

Information requested in the Table above should be provided for each link whether Direct-to Earth, Relay, or other.

Table 3-3: Sample Station Support Requirements Table

Mission Phase		Year of Support	Subnetwork Requested	Hours per Track	No. Tracks Per Week	No. Weeks Required
1	Launch	2006	34BWG	8	21	2
2	Cruise	2006	34BWG	4	2	5
3	Cruise	2007	34BWG	4	2	33
4	TCM-1	2007	34HEF	8	7	2
5	Cruise	2007	34BWG	4	2	2
6	TCM-2	2007	34BWG	8	7	2
7	Planetary Orbit Insertion	2007	34HEF	8	21	3
7	Orbit Operations	2007	70	4	7	10
8	Orbit Operations	2008	70	4	7	52

4.0 REFERENCES

Prospective users of DSMS facilities can obtain additional information from the following documents:

1. *Radio Regulations*, International Telecommunications Union, Geneva, Switzerland, Latest Edition.
2. *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications & Information Administration, U.S. Department of Commerce, Washington D.C., Latest Edition. **Information is available at:** <http://www.ntia.doc.gov/osmhome/redbook/redbook.html>
3. Consultative Committee for Space Data Systems (CCSDS). Blue Books published by the CCSDS Secretariat, NASA Headquarters, Washington D. C. 20546. **Copies of CCSDS Recommendations and Reports are available at:** http://www.ccsds.org/blue_books.html. **Copies of Red CCSDS Recommendations are at:** http://www.ccsds.org/red_books.html.
4. *Handbook of the Space Frequency Coordination Group*, ESA Frequency Manager and SFCG Secretariat, European Space Agency Headquarters, 8-10 Rue Mario Nikis, 75738 Paris, France. **Copies of the document are available at:** <http://www.sfcgonline.org/>
5. *DSMS Future Missions Planning Office* homepage. **Web site located at:** <http://deepspace.jpl.nasa.gov/advmiss>
6. *DSMS Services Catalog*, Organization 900, Jet Propulsion Laboratory, Pasadena, California, latest edition), **Copies available at:** <http://deepspace.jpl.nasa.gov/advmiss>
7. *GSFC Mission and Data Services, 2002 Catalog*; Goddard Space Flight Center, Greenbelt, Maryland 20771. **Copies of the document are available at:** <http://ccs.honeywell-tsi.com/cco>

5.0 GLOSSARY

AF	Aperture Fee
AF'	Aperture Fee discounted for Multiple Spacecraft per Aperture applications
A _w	Aperture Weighting (For costing DSN stations)
AMMOS	Advanced Multi-Mission Operations System
AO	Announcement of Opportunity
ARQ	Automatic Repeat Queuing
ASI	Agenzia Spaziale Italiana (Italy)
b/s	Bits per second
BWG	Beam Wave Guide (Refers to specific DSN 34M antennas)
Category A	Missions whose distance from Earth is $< 2 \times 10^6$ km.
Category B	Missions whose distance from Earth is $\geq 2 \times 10^6$ km.
CCSDS	Consultative Committee for Space Data Systems
CTT	Compatibility Test Trailer
CFDP	CCSDS File Delivery Protocol
CLTU	Command Link Transmission Unit
CNES	Centre National d'Etudes Spatiales (France)
Code M	NASA Headquarters Office of Space Flight
Code S	NASA Headquarters Office of Space Science
Code Y	NASA Headquarters Office of Earth Science
dB	Decibels
dBi	Decibels (relative to an isotropic radiator)
DDOR	Delta Differenced One-way Range
DLR	Deutsches Zentrum für Luft- und Raumfahrt (Germany)
DSA	DSMS Service Agreement (formerly PSLA in DSN)
DSMS	Deep Space Mission System
DSN	NASA's Deep Space Network
DTF-21	Development Test Facility-21 (Compatibility test area located at JPL)
EES	Earth Exploration Satellite (A communications service designated by the ITU)
ESA	European Space Agency
F _c	Frequency of Contacts (For costing DSN stations)
FY	Fiscal Year
GHz	Gigahertz (1×10^9 cycles per second)
GN	NASA's Ground Network
GRGT	Guam Remote Ground Terminal
HEF	High Efficiency (Refers to specific DSN 34M antennas)
Hr	Hour
HSB	High Speed Beamwaveguide (Refers to specific DSN 34M antenna)
Hz	Hertz (cycles per second)
IMT-2000	International Mobile Telephone-2000 (3 rd generation mobile telephone system)
IND	Interplanetary Network Directorate (JPL Program Office)
ISAS	Institute of Space and Astronautical Science
ITU	International Telecommunications Union
JPL	Jet Propulsion Laboratory

NASA's Mission Operations and Communications Services

K	Kilo (1×10^3)
K _A -Band	Frequency band: Deep Space (Category B) 31.8-32.3 GHz downlink
Km	Kilometers
LEOP	Launch and Early Orbit Phase
M	Meters
MA	Multi-Access
MD	Maryland (abbreviation)
MHz	Megahertz (1×10^6 cycles per second)
MSPA	Multiple Spacecraft per Aperture
NASA	National Aeronautics and Space Administration
NASDA	National Aeronautics and Space Development Agency (Japan)
NPG	NASA Procedures and Guidelines
NTIA	National Telecommunications and Information Administration
PI	Principal Investigator
POCC	Project Operations Control Center
PSLA	Project Service Level Agreement
r	Range (Earth to spacecraft)
RAF	Return All Frames
R _B	Base Rate (For costing DSN stations)
RCF	Return Channel Frames
RFS	Radio Frequency Subsystem
SA	Single Access
SCDS	Space Communications and Data Systems
SFCG	Space Frequency Coordination Group
SLE	Space Link Extension
SN	NASA's Space Network (TDRSS)
STGT	Second TDRSS Ground Terminal
TCM	Trajectory Correction Maneuver
TDRSS	Tracking and Data Relay Satellite System
WSGT	White Sands Ground Terminal
X-Band	Frequency band: 7145-7235 MHz uplink; 8400-8500 MHz downlink